Article

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RSE

# A FISH KILL RELATED TO AN ACID-METAL SPILL (LITTLE SACKVILLE RIVER, NOVA SCOTIA, CANADA)

*Une mortalité de poissons liée à un déversement métal-acide (Rivière Little Sackville, Nouvelle-Écosse, Canada)*

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## ABSTRACT

This paper documents the aqueous transport of acidic drainage in the Little and Main Sackville Rivers in Nova Scotia, and contributes to a better general understanding of the movement and duration of impact in such an event. Acidic drainage has been often noted as a major environmental hazard in mainland Nova Scotia. In addition to the details of the distribution and dispersal of metal concentrations in the Sackville Rivers ecosystem, some of the effects upon the aquatic organisms in the area are presented.

Both an automated and hand-held devices were used to obtain physical water quality both prior to and after the event. The environmental impacts of the contaminant are discussed in terms of their immediate effects. The immediate effects in the mixing zone, where toxicity occurred, were at the entrance of the acid-bearing outflow, where there was a presence of mixing with the higher pH waters in the main channel. More than 4000 dead fish were counted (including approximately 300 American eels (*Anguilla rostrata*), 1000 one-year-old salmon (*Salmo salar*), 150 two-year-old salmon, 24 small-mouth bass (*Micropterus dolmieui*) and 24 suckers (*Catostomus commersonii*), in addition to minnows (specific species unidentified), small gaspereau (*Alosa pseudoharengus*), brook trout (*Salvelinus fontinalis*), freshwater mussels (specific species unidentified), and a snapping turtle (*Chelydra serpentina*). It is most likely that the fish kill resulted from rapid suffocation due to metal flocculants clogging the gills. It was in this zone where dissolved metals precipitated (Al, Fe, Cu).

***Key Words: fish kill, contamination, impacts, acid drainage, metals***

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## RÉSUMÉ

Le drainage acide a souvent été identifié comme un danger environnemental majeur. Cet article décrit un épisode d'acidification qui s'est produite dans la rivière Sackville, Nouvelle Ecosse, Canada. Il contribue à offrir une meilleure compréhension de la durée d'impact d'un tel événement. Outre les détails concernant la distribution et le dispersement des concentrations métalliques dans la rivière Sackville, cet article souligne aussi quelques effets subis par les organismes aquatiques de la rivière.

Pour suivre la qualité de l'eau avant, pendant et après l'épisode, des échantillons d'eau ont été prélevés à l'aide d'un appareil mécanique automatisé et analysés pour diverses variables (pH ; conductivité ; ions majeurs ; métaux traces); certaines mesures (pH ; conductivité, turbidité ; oxygène dissous ; température) ont également été effectuées manuellement. Les impacts environnementaux les plus évidents se sont manifestés dans la zone de mélange, où les eaux acides ont rencontré les eaux de la rivière Sackville principale, qui avaient un pH nettement plus haut. Plus de 4000 poissons sont morts, y compris environ 300 anguilles américaines (Anguilla rostrata), 1000 saumons âgés d'un an (Salmo salar), 150 saumons de deux ans, des achigans à petite bouche (Micropterus dolmieui) et 24 meuniers noirs (Catostomus commersonii), en plus de menés (espèces non identifiées), de petits gaspareaux (Alosa pseudoharengus), de truites mouchetées (Salvelinus fontinalis), des moules d'eau douce (espèces non identifiées) et une tortue mordante (Chelydra serpentina). Il est fort probable que les poissons sont morts d'asphyxiassions rapide due à la présence de métaux floculés qui leur aurait bouché les branchies. C'était dans cette zone que les concentrations de métaux dissous se précipitaient (Al, Fer, Cu).


***Mots clefs: extermination des poissons, contamination, impacts, drainage acide, métaux***

## 1. INTRODUCTION

Acid drainage is not limited to mining areas, as widespread impacts have been documented at sites ranging from highway and airport construction to redevelopment of sites with acid rock infill to the digging of municipal services and pipelines (ZENTILLI and FOX, 1997). Acid drainage occurs when minerals containing reduced forms of sulfur (pyrites, other sulfides) are oxidized upon exposure to water and oxygen. The oxidation process results in production of strong acids, such as sulfuric acid, which mobilize acid-soluble metals, including iron (Fe), aluminum (Al), copper (Cu), zinc (Zn) and others depending on the mineralogy of the disturbed area. The mixture of acid and dissolved metals creates a "severe environment for aquatic organisms" (SOUCEK *et al.*, 2001), including low pH, high conductivity and elevated metal concentrations.

Acid mine drainage (AMD) and acid rock drainage (ARD) have been reported as sources of environmental contamination as well as ecological disasters such as fish kills (e.g. BERRYMAN and JALBERT, 2004; McKNIGHT and FEDER, 1984). Physiological and toxicological responses of freshwater fishes to the acute toxicity of aqueous aluminum, a common dissolved metal resulting from AMD, have been well documented (CALTA, 2002; EXLEY *et al.,* 1996; FROMM, 1980; NEVILLE, 1985; POLÉO, 1995). Similarly, acute aqueous aluminum toxicity is known to adversely affect benthic macroinvertebrates (SOLÀ *et al.*, 2004; SOUCEK *et al.*, 2000a; 2000b). Concentrations of some elements, such as Al, may be 4 to 5 orders of magnitude above tolerable limits. Aluminum rarely occurs naturally in water at concentrations greater than a few tenths of a milligram per liter, and when present at high concentration, can have the most severe adverse effects on stream aquatic life (BROWN and SADLER, 1989; HEM, 1970). Most freshwater fish are adversely affected at pH less than approximately 5 (ZENTILLI and FOX, 1997).

Many coal mining regions of the United States have streams affected by AMD. The United States Environmental Protection Agency (US EPA) has identified AMD as the greatest water quality problem in the Appalachian region of the US as well as in regions of Colorado (Office of Surface Mining, 1995; SHARPE *et al.*, 1984; THEOBALD *et al.*, 1963). Many other parts of the world have had similar cases of AMD impacts on receiving waters (GRIMALT *et al.*, 1999; LEIVESTAD and MUNIZ, 1976; PRAT *et al.*, 1999). ARD and AMD potential are cited as major environmental hazards in mainland Nova Scotia (FEETHAM *et al.*, 1997; FOX *et al.*, 1997; ZENTILLI and FOX, 1997). Other researchers have similarly reported on the fluvial transport and fate of Class A metals (DUFFUS, 2002) in other regions (e.g. MILLER, 1997) and in other parts of Nova Scotia (e.g. WONG *et al.*, 1999).

This paper describes the impact of an AMD event in the Little Sackville River (LSR) watershed in Halifax, Nova Scotia, Canada. The LSR is a southerly flowing river, approximately 14 km in length, which meanders through residential and commercial districts of Middle and Lower Sackville. The drainage basin area is 15.5 km2 and the LSR is a second order stream to the Sackville River, which is the only river that flows into Halifax Harbour (NOLAN DAVIES ASSOCIATES, 1987). The physiography of the area is dominated by drumlin terrain with elevations rising to 145 m. The geology is comprised predominantly of slates, overlain by thick glacial drift deposits and rocky soils. The watershed has been heavily developed and many features (including wetlands and water courses) have been altered over previous decades as a result of urbanization.

Early on the evening of Friday, July 12, 2002, homeowners backing onto the (LSR) called the President of the Sackville Rivers Association (SRA). A strange "chemical" odour and discoloration of the river was noted, and dead fish were observed. Officials were notified and members of the SRA went out to the river to inspect the site for themselves. A massive fish kill was observed. Photos were taken and water samples were collected. The visual contamination was quickly traced to an outlet stream coming into the river from a holding pond adjacent to a shopping complex (Figure 1, Site 4). The holding ponds had been designed to contain runoff from the large parking lot (contaminants, salts from winter snow removal, etc.) from entering the adjacent LSR.

The decisive factors that contributed to the fish kill in the LSR are not well documented. According to the environmental inspection officers for both the Province of Nova Scotia and the Halifax Regional Municipality, the acidic drainage event occurred as a result of a water main break that drained over an acidic rock infill. The infill had been overlain by a shopping complex, but once the complex was demolished, the infill was exposed and reactions occurred in the presence of oxygen and water, flowing by pipe into the third holding pond (Site 3) and ultimately over-flowing that pond and entering the LSR at Site 4. By the end of the following week, at least 4000 fish had been killed, and a 7 km stretch of the river had been impacted.

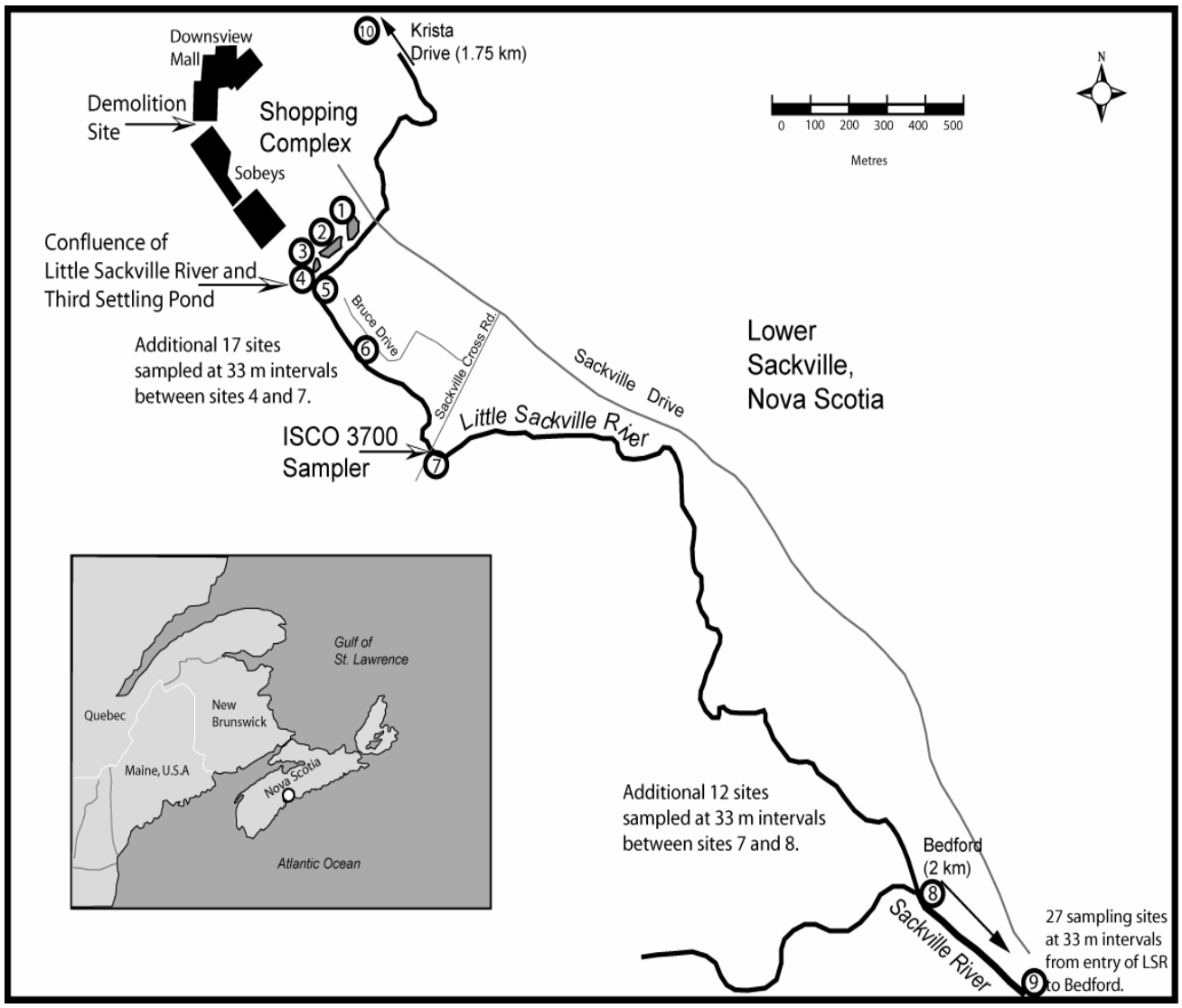


**Figure 1. Study Area.**
***Zone de l'étude.***

## 2. MATERIALS AND METHODS

Research had been initiated in the LSR in May, 2002 to investigate amounts of suspended sediment in the river and to link the impacts of urbanization and land disturbance to increased amounts of eroded material flowing into the river. As a result of this joint research initiative between the SRA and a researcher at Saint Mary's University, three automatic water samplers (ISCO 3700) had been secured on the banks of three locations in the stream. One was located at the Sackville Cross Road bridge (Site 7), one at Krista Drive (Site 10) and another a few kilometers upstream from Site 10. Figure 1 illustrates the locations for the sections of the rivers and surrounding watershed that are mentioned throughout the paper. All three samplers had been programmed to collect water samples at 6 hour intervals (4:00, 10:00, 16:00, 22:00). The other two samplers were located outside of the present study area (upstream from the outlet).

The ISCO 3700 automatic samplers consist of an intake line/strainer, a peristaltic pump, sample containers, and a controller. The samplers have a base of 24 one liter glass bottles. Bottles receive 450 mL samples every 6 hours, with a purge cycle to minimize cross-contamination of samples. The set of 24 bottles, each with approximately 450 mL of sample, would therefore be collected every six days and a new set would be replaced in the sampler. In addition to standard samples, the field technicians collected blanks and field duplicate samples. Care was taken with regards to equipment handling, container handling and storage, and record keeping. Sample collection equipment and non preserved sample containers were rinsed three times with sample water before the actual sample was obtained. The ISCO bottles were cleaned in the laboratory using the standard US EPA bottle cleaning procedure (US EPA Method 1669, 1996).

In addition to the automated ISCO water samples, physical water quality data (pH, conductivity, dissolved oxygen, temperature, and turbidity) were collected twice weekly using a Horiba U-10 Water Quality Monitor. This equipment was calibrated with a two-point calibration prior to each field session. Calibration was undertaken in accordance with the US EPA standard calibration guidelines (HUNT *et al.,* 1996). Care was always taken in handling the probes while taking measurements. They were held in the water column, in deep enough water to not touch the bottom. The field technicians stood downstream from the probe to avoid stirring up sediment. Water sampling from both the automated sampler and the handheld equipment was conducted according to the Australian standards guidelines (STANDARDS AUSTRALIA, 1998), including quality assurance and quality control (QA/QC) measures.

At Site 7, physical water quality parameters (using the Horiba U-10) were gathered on July 11, 2002 at approximately 11:15 a.m. (unbeknownst to the researcher that this would be 24 hours prior to the contamination event). Physical water quality parameters subsequent to the contamination event (July 12 – 18, 2002) were gathered using the Horiba U-10 as well. Water samples were analyzed by ICP/Atomic Emission Spectrometry (US EPA, 1995) for metal constituents at an accredited environmental laboratory (PSC Analytical).

## 3. RESULTS

Monitoring that was in place prior to the contamination event fortunately provides an overview of general water quality in the pre-impact state. At Site 7 (Figure 1) pH was relatively neutral, ranging from 7.43 to 7.69 between June 27 and July 11, 2002. Conductivity values (0.50-0.60 mS $cm^{-1}$) and dissolved oxygen (9.0-10 mg $L^{-1}$) were typical of an unimpacted freshwater system (Table 1). By July 12, 2002, the pH had dropped to 4.4 and the conductivity had risen to 950 mS $cm^{-1}$ (Table 2). The dramatic drop in pH can clearly be seen in Figure 2, on the evening of July 12.

On the evening of July 12/02, when the contaminant plume had been first observed by residents in Lower Sackville (at Site 6 on Figure 1), water samples were obtained at three locations (Sites 4, 5 and 6 on Figure 1). At the time, the substances in the water were unknown. In addition to the three samples taken on the night of July 12, two "background" samples were

**Table 1.** **Physical water quality at Site 7 prior to the contamination event.**
***Tableau 1.*** ***Qualité physique de l'eau au Site 7 avant la contamination.***

| Date/Time | Temperature °C | pH | Conductivity mS $cm^{-1}$ | Dissolved Oxygen mg $L^{-1}$ |
|---|---|---|---|---|
| June 27/02 11:45 AM | 17.4 | 7.69 | 0.581 | 9.98 |
| July 4/02 12:10 PM | 21.7 | 7.46 | 0.603 | 9.03 |
| July 8/02 10:45 AM | 18 | 7.43 | 0.601 | 9.3 |
| July 11/02 11:15 AM | 18.2 | 7.52 | 0.502 | 9.79 |

**Table 2. Physical water quality at Site 7 subsequent to the contamination event.**
***Tableau 2. Qualité physique de l'eau au Site 7 après la contamination.***

| Date/Time | Temperature °C | pH | Conductivity mS $cm^{-1}$ | Dissolved Oxygen mg $L^{-1}$ |
|---|---|---|---|---|
| July 12/02 8:00 PM | unknown | 4.4 | 950 | Unknown |
| July 15/02 11:00 AM | 19.3 | 4.48 | 1.12 | 7.81 |
| July 18/02 11:55 AM | 15.8 | 4.75 | 0.725 | 8.83 |
| July 19/02 11:50 AM | 18.4 | 7.09 | 0.45 | 8.61 |
| July 25/02 12:15 PM | 19.7 | 7.19 | 0.455 | 9.29 |

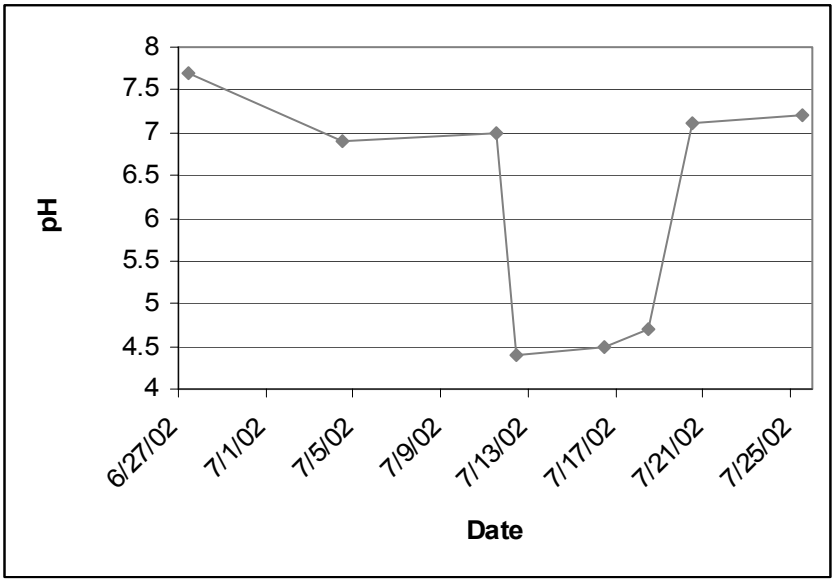


**Figure 2. pH at Site 7, Little Sackville River from June 27/02 to July 25/02.**
***pH au Site 7, rivière « Little Sackville » du 27 juin 2002 au 25 juillet 2002.***

analyzed. One of the background samples was taken from Site 7 on a date prior to the event (June 15, 2002) and the other was obtained from Site 10. After the contaminant moved through the river, every analyte concentration was elevated. One of the most dramatic increases was Al. It rose from 0.02 – 0.16 mg $L^{-1}$ at Sites 7 and 10 respectively to 180 mg $L^{-1}$ at Sites 4 and 5 and 160 mg$L^{-1}$ at Site 6 after the contaminant plume moved through the system (Table 3). Other notable increases include SO4 which rose from 14-26 mg$L^{-1}$ (Sites 10 and 7) to 1500 mg $L^{-1}$ at Site 4 and 1600 mg $L^{-1}$ at Site 5.

In order to determine the increase for each analyte (Table 4), the average of the two pre-contamination sites was compared to the average of the two outflow sites. Aluminum had the greatest increase above background levels with a 2000x increase, followed by Ni with a 600x increase and Zn with a 230x increase. Every analyte tested showed a substantial increase over background levels. When compared to the guidelines for freshwater aquatic life (last column of Table 3), the levels are well above suitable levels for aquatic species, which contributed to their high mortality.

In an effort to trace the source of the contaminant, data were obtained using the Horiba U-10, as a quick but accurate method to obtain pH, conductivity and dissolved oxygen. On July 16, 2002, water quality parameters were tested at the holding ponds adjacent to the shopping complex and parking lot (Sites 1-3, Figure 1). The physical water quality for the holding ponds is summarized in Table 5. Conductivity is somewhat higher than typical in-stream values, and dissolved oxygen is lower, but pH values are typical of in-stream values. Site 3 is situated furthest back from Sackville Dr., and is directly adjacent to the shopping complex. The initial reading in this pond was taken where the Second Pond spills into the third. The second reading in the Third Pond was taken directly at the drainage grate. Both pH (lowered values) and conductivity (increased values) towards the main drain of site 3 indicated a potential source of the contamination. Water quality readings were then taken at an outlet from Site 3, which flows directly in to the LSR (Site 4). Readings from Site 4 were compared to those upstream from the outfall and there was a notable difference (Table 6). The difference between water quality readings within a metre's distance apart changed from a

**Table 3.** **Analyte concentrations for sections of the LSR before and after the contaminant event (*values that are provided by the CCME Canadian Water Quality Guidelines, 2002).**

***Tableau 3.*** ***Concentrations de divers analytes pour les sections de la rivière « Little Sackville » avant et après la contamination. (*valeurs fournies par le CCME « Canadian Water Quality Guidelines », 2002).***

| | Pre-contamination | | Post-contamination | | | |
|---|---|---|---|---|---|---|
| **Analyte mg $L^{-1}$** | **Site 7 June 15/02** | **Site 10 July 11/02** | **Site 4 July 12/02** | **Site 5 July 12/02** | **Site 6 July 12/02** | **Guidelines for Freshwater Aquatic Life*: mg $L^{-1}$** |
| Na | 104 | 32.3 | 301 | 299 | 84.6 | |
| K | 3.1 | 2.3 | 6.2 | 6.5 | 6.7 | |
| Ca | 37.8 | 14.5 | 100 | 105 | 37.2 | |
| Mg | 5.8 | 2.5 | 106 | 97 | 12.5 | |
| $SO_4$ | 26 | 14 | 1500 | 1600 | 160 | |
| Cl | 190 | 56 | 530 | 480 | 140 | 0.002 |
| Al | 0.020 | 0.160 | 180 | 180 | 160 | 0.005-0.1 |
| Cu | 0.006 | 0.004 | 0.230 | 0.230 | 0.084 | 0.002-0.004 |
| Fe | 0.430 | 2.0 | 13 | 13 | 22 | 0.3 |
| Mn | 0.140 | 0.830 | 9.3 | 9.8 | 3.4 | |

**Table 4.** **Increase for each analyte, as a result of the contamination event.**

***Tableau 4.*** ***Augmentation pour chaque analyte, résultant de la contamination.***

| Analyte mg/L | Pre-contamination sites: average | Outflow sites average | Increase (x) |
|---|---|---|---|
| K | 2.7 | 6.35 | 2 |
| Ca | 26.2 | 103 | 4 |
| Ba | 0.0315 | 0.125 | 4 |
| Cl | 123 | 505 | 4 |
| Na | 68.2 | 300 | 4 |
| Fe | 1.22 | 13 | 8 |
| Mn | 0.485 | 9.55 | 20 |
| Mg | 4.15 | 102 | 24 |
| Cu | 0.005 | 0.23 | 46 |
| $SO_4$ | 20 | 1550 | 78 |
| Zn | 0.011 | 2.55 | 230 |
| Ni | 0.003 | 1.8 | 600 |
| Al | 0.09 | 180 | 2000 |

**Table 5.** **Water quality at Sites 1, 2 & 3, adjacent to the Little Sackville River.**
***Tableau 5.*** ***Qualité de l'eau aux Sites 1, 2 et 3, adjacents à la rivière « Little Sackville ».***

| Location | Date/Time | Temperature °C | pH | Conductivity mS cm$^{-1}$ | D.O. mg L$^{-1}$ |
|---|---|---|---|---|---|
| Site 1: Reading 1 | July 16/02 11:20 | 18 | 6.64 | 1.15 | 1.18 |
| First Pond: Reading 2 | July 16/02 11:22 | 19 | 6.97 | 1.43 | 4.96 |
| Site 2: | July 16/02 11:25 | 20.8 | 7.64 | 1.42 | 4.97 |
| Site 3 (furthest point up) | July 16/02 11:31 | 14.6 | 6.72 | 2.83 | 4.86 |
| Third Pond (Main Drain) | July 16/02 11:35 | 15.5 | 4.05 | 3.84 | 7.62 |

**Table 6.** **Water quality at the outlet from Pond 3 (Site 3), into the Little Sackville River, and upstream of the outlet.**
***Tableau 6.*** ***Qualité de l'eau à la sortie de l'étang (Site 3), dans la rivière « Little Sackville », et en amont de la sortie.***

| Location | Date/Time | Temperature °C | pH | Conductivity mS cm$^{-1}$ | D.O. mg L$^{-1}$ |
|---|---|---|---|---|---|
| Site 3 (top of outfall to LSR) | July 16/02 12:00 | 16.9 | 4.12 | 4.07 | 7.13 |
| Site 4 | July 16/02 12:15 | 17.6 | 4.34 | 2.3 | 8.42 |
| LSR: Upstream from outfall | July 16/02 | 18.1 | 6.7 | 0.526 | 8.65 |

relatively normal pH of 6.7 and conductivity of 0.526 mS cm$^{-1}$ immediately upstream of the outfall to a pH of 4.34 and a conductivity of 2.3 mS cm$^{-1}$ where the contaminant plume immediately entered the LSR.

Following the findings at the drain in the Third Pond (Site 3) on July 16, the concern shifted to the distance that the contamination had traveled downstream. On the afternoon of July 16, readings were taken at the mouth of the LSR (Site 8), and were taken upstream at 33 m intervals, working back towards the contaminated outflow (between sites 7 and 8 on Figure 1). Figure 3 depicts the pH and conductivity of the LSR from the mouth upstream towards the outflow and entrance point of the contaminant plume. Conductivity and pH were relatively normal at Site 8 and within the suitable range for freshwater aquatic habitat, but readings obtained approximately 33 metres upstream from the mouth were unsuitable for aquatic life and remained so for a distance of just over 500 m.

On the evening of July 16, approximately 15 mm of precipitation fell in the region. Concerns regarding the downstream flush of the contaminants were high. On Wednesday, July 17, 2002, monitoring efforts were concentrated on the main Sackville River. Given the deteriorating water quality in the LSR as far as the mouth, it was of great concern that the contaminants had likely spread down the main Sackville River (SR), especially with the rainfall the previous evening.

Results of the water quality data collection on the 17th of July are illustrated in Figure 4. Data were collected in Bedford (Site 9), and samples were taken upstream at 88 m intervals towards the mouth of the LSR. The water samples were taken starting from 11:21 in Bedford through to 16:50 at the mouth of the LSR. The decline in the pH between 400 m to 100 m upstream from Bedford illustrates the flushing effect as the contaminants moved through the system. The improvement in the water quality towards the mouth of the LSR illustrates the "cleansing effect" as the higher flow moved the contaminants in a downstream direction. From 15:00 on July 16 to 16:50 on July 17, the water quality had started to improve, with pH up (from 5.9 to 6.5), and conductivity down as a result of variations in the water's chemical composition (from 0.50 mS cm$^{-1}$ to 0.27 mS cm$^{-1}$).

The increase in the conductivity, inverse to the decrease in pH, also illustrates the downstream flushing effect of the contaminants after the heavy precipitation the night before. Due to the apparent improvement in the water quality towards the mouth of the LSR later in the afternoon of July 17, it was hoped that the water quality further upstream in the LSR was also improving. On July 18, water quality was tested

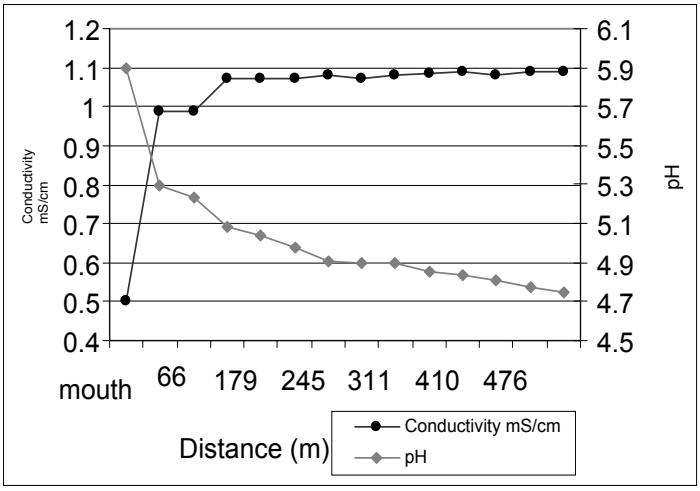


**Figure 3. pH and conductivity of the LSR from the mouth to 509 m upstream on July 16, 2002.**
***pH et conductivité de la rivière « Little Sackville» de l'embouchure jusqu'à 509 m en amont, le 16 juillet 2002.***

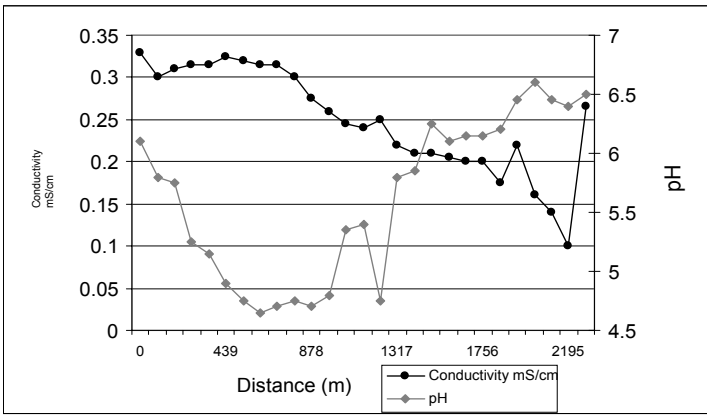


**Figure 4. pH and conductivity of the main Sackville R. on July 17/02, from Bedford to LSR mouth (2195 m).**
***pH et conductivité de la rivière « Main Sackville» le 17 juillet 2002, de Bedford jusqu'à l'embouchure de la rivière « Little Sackville» (2 195 m).***

from the Third Pond (Site 3) downstream to the Sackville Crossroads (Site 7). The pH remained around 4.7, although the conductivity had decreased somewhat.

Six days after the initial contamination was noted, the pH in the uppermost contaminated reaches of the LSR remained at very low levels (4.75). There were no dead fish observed after approximately the fourth day after the event, as most of the species in the river had likely already died from the initial impact. In the late afternoon of July 18, the Nova Scotia Department of the Environment drained the contents of the pond into tankers and installed a dam at the top of the outflow. The following day (Friday, July 19), the same reaches were tested for water quality in order to determine whether the damming and draining of the contaminated pond had resulted in an improvement in the river. The pH had changed significantly from the day before, with improvements at Site 4 and further downstream (Table 7). Pockets of low pH could be traced in areas where relatively large accumulations of the contaminant plume were still settling and on the bottom of the channel (Figure 5). There was a large difference in the water quality as judged from the change between the July 18 readings and the July 19 readings. The recovery of the water quality to pre-contamination conditions was almost immediate. By July 20th, the water quality was returning to pre-contamination conditions (Table 7).

# 4. DISCUSSION

The environmental impacts of the contaminant event can be discussed in terms of the immediate effects and the longer-term effects. The immediate effects in the mixing zone, where extreme toxicity occurred (ROSSELAND *et al.*, 1992), were at the entrance of the acid-bearing outflow, where there was mixing with the higher pH waters in the main channel. At this point, with pH values in the highly acidic range, the Al dissolved concerntrations were supersaturated and an aluminum hydroxide precipitate formed. The precipitate was observed on the bottom of the channel in this zone (several cm thick and initially whitish-grey in appearance and then eventually taking on the coloration of the surrounding clays) and extended several meters downstream. Acute toxicity in mixing zones has been documented in other cases (HENRY

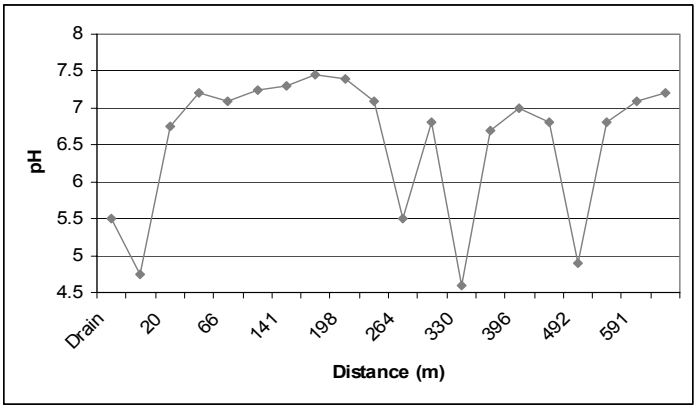


**Figure 5. pH in the outlet to the Little Sackville River and in the LSR on July 19/02 (from the Drain in the contaminated pond (Site 3) downstream to 591 m).**
***pH de la sortie vers la rivière « Little Sackville » et dans la rivière « Little Sackville » le 19 juillet 2002 (du drain de l'étang contaminé (Site 3) en aval jusqu'à 591 m).***

**Table 7.** **Water quality at the outlet from Pond 3, into the Little Sackville River (July 18-20, 2002).**
***Tableau 7.*** ***Qualité de l'eau à la sortie de l'étang, dans la rivière « Little Sackville » (18-20 juillet 2002).***

| Location | Date/Time | Temperature °C | pH | Conductivity mS cm$^{-1}$ | D.O. mg L$^{-1}$ |
|---|---|---|---|---|---|
| Drain at Third Pond | July 18/02 10:25 AM | 15.3 | 4.06 | 3.18 | 8.1 |
| | July 19/02 10:45 AM | 19.8 | 5.45 | 3.55 | 2.45 |
| | July 20/02 9:20 AM | 17 | 6.4 | 0.136 | 8.14 |

*et al.*, 1999; ROSSELAND *et al.*, 1992). Mixing zones are often apparent, based on the presence of visible metal precipitates that are attached to the substratum in the water column below the confluence (THEOBALD *et al.*, 1984), and this was most obvious in the LSR case. Precipitation of Fe or Al (or both) on fish gills, and the rapid decrease in pH as the contaminants entered the main channel both likely contributed to the high fish mortality. The gills of the dead fish were clogged with flocoulated metal and it was interpreted that death was caused by rapid suffocation. Other studies (e.g. BERRYMAN and JALBERT, 2004) have documented similar scenarios of rapid suffocation resulting from acidic drainage and floculated metal.

More than 4000 fish were counted (including approximately 300 American eels (*Anguilla rostrata*), 1000 one-year-old salmon (*Salmo salar*), 150 two-year-old salmon, 24 small-mouth bass (*Micropterus dolmieui*) and 24 suckers (*Catostomus commersonii*), in addition to minnows (specific species unidentified), small gaspereau (*Alosa pseudoharengus*), brook trout (*Salvelinus fontinalis*), freshwater mussels (specific species unidentified), and a snapping turtle (*Chelydra serpentina*). "Probably more salmon than you'd see in the wild in your entire life." (HEBDA, 2002).

It is interesting to note that when inspection officers from the Nova Scotia Department of Environment and Labour (NSDOEL) arrived (July 12-13) to investigate the potential source and cause of the fish kill, they only tested for dissolved oxygen. This parameter was technically irrelevant in this case, as dissolved oxygen levels remained good throughout the impacted and unimpacted sections of the LSR. Had they monitored different and more relevant variables, the cause and source of the contaminants might have been determined much sooner.

Although it is hard to know what the longer-term impacts might be, the owner of the property where the acidic contaminant plume flowed from was required to contract a consultant to detect effects in the aquatic environment of the LSR by monitoring, among other parameters, aquatic invertebrates and fish. The executive summary of the consultants' final report states that "Effects due to the accidental flush of acidified water were not detected." (Jacques Whitford, 2004, p. iii). Their sampling regime was initiated ten months after the event. This report makes no mention of the effects being short- or long-term. It is also questionable to compare upstream and downstream impacts ten months after the event. Invertebrate sampling, undertaken in May, August and October of the following year, indicate that "the invertebrate habitat is available and populations are thriving within the sampled sections of the LSR." (Jacques Whitford, 2004, p.17). Electrofishing results, undertaken one year later, at both upstream and downstream sites of the entrance point of the contaminant were inconclusive and it was not apparent that "fish numbers varied in the LSR due to the accidental, one-time discharge…" (Jacques Whitford, 2004, p.20).

It remains to be seen if there are longer-term impacts from the discharge of acid drainage into the LSR. This event can serve as a reminder of the significant potential of acid drainage to cause severe impacts on freshwater ecosystems. There remains a need for a more comprehensive, multi-jurisdictional response plan for such an event. Although a Regional Environmental Emergencies Team (REET) team was convened by Environment Canada, the response was slow and the impacts continued days after the outlet flowed into the LSR. This event may serve as a useful case to improve upon future management and emergency responses to environmental emergencies.

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